

ORIGINAL ARTICLE

Wastewater exposure and health—a comparative study of two occupational groups

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Aims: To investigate whether wastewater workers are at increased risk of developing cancer.

Methods: Two cohorts of workers employed by the City of Copenhagen, 591 wastewater workers and 1545 water supply workers (controls), were followed from 1965 until 1998. These two cohorts were compared in terms of cause specific mortality and cancer incidence.

Results: The wastewater workers' mortality exceeded that of the controls (relative risk (RR) = 1.25, 95% CI: 1.03 to 1.51). A similar small excess was seen for cancer incidence (RR = 1.27, 95% CI: 0.97 to 1.67). Though rare, there was a strongly increased incidence of primary liver cancer among the wastewater workers (RR = 8.9, 95% CI: 1.5 to 51.5).

Conclusion: The excess mortality seen among the wastewater workers was smaller than originally feared. It may partly have been due to their occupational exposure, and for preventive purposes, exposure to wastewater and sludge should be minimised. The possibility that sewage exposure confers an increased risk of primary liver cancer deserves further investigation.

Exposure to sewage involves potential intake of pathogens, toxins, and industrial wastes. While acute and subacute effects are well described,^{1–6} the evidence relating to long term effects is more scant and less consistent.^{7–9} Some of the studies on long term effects have indicated a slight increase in the total mortality and in the incidence of cancer,^{7–9} while analyses on specific cancer sites have yielded non-consistent observations comprising excess numbers of laryngeal cancer and primary liver cancer,⁹ and of cancer of the prostate gland, the nose and nasal sinuses, and the stomach.⁸

Wastewater workers may be exposed by inhalation of aerosols and gasses, by dermal contact, and by ingestion. The microbial agents include Gram negative bacilli such as *Klebsiella* spp and *Escherichia coli*, *Clostridium perfringens*, faecal streptococci, *Leptospira* spp, hepatitis virus, enterovirus, and *Aspergillus* spp.^{10–12} In addition, the workers may be exposed to such agents that may be produced by or from these organisms, including exotoxins, endotoxins, butyl acetate, and hydrogen sulphide.¹² With regard to industrial wastes found in the Copenhagen sewer system, the list of potentially toxic

substances includes heavy metals, chlorinated solvents (chloroform, perchloroethanol, and dichloroethane), other solvents (xylene, toluene, benzene, and alcohols), formaldehyde, antibiotics, pesticides, dyes, detergents, phenols, and polycyclic aromatic hydrocarbons.¹²

For decades, the Union of Copenhagen Wastewater Workers has been engaged in occupational health and safety matters, and the workers have been concerned about possible long term effects of exposure to sewage. A follow up study from 1959 to 1981, covering 142 Copenhagen wastewater workers, showed a slightly increased mortality (SMR = 1.15) compared to that of Copenhagen males, a difference that tended to increase during the period studied.⁷ Interview and questionnaire based health surveys have revealed a high frequency of acute gastrointestinal symptoms among Copenhagen wastewater workers.^{6, 13} A clinical survey covering 77 Copenhagen wastewater workers in 1976 showed increased leucocyte counts and immunoglobulin A levels; the prevalence of hepatitis seromarkers was 81% for antibodies towards type A (anti-HAV), 9% towards type B (anti-HBV), and 0% for the hepatitis B surface antigen (HbsAg).¹⁴ Three workers reporting a history of jaundice during their wastewater employment all tested positive for anti-HAV; one also had antibodies against *Leptospira icterohaemorrhagica*.¹⁴

In this paper we present a follow up study on cause specific mortality and cancer incidence. Based on the literature, our interest was directed towards nasal cancer, laryngeal cancer, stomach cancer, liver cancer, and prostate cancer.

Main messages

- The mortality and cancer morbidity was slightly increased among Copenhagen wastewater workers.
- The incidence of primary liver cancer was significantly increased among Copenhagen wastewater workers.

Policy implications

- The wastewater workers' exposure to sewage should be minimised, an objective that may be achieved by a thorough hygienic scrutiny of every installation and work procedure and by informing the workers about the potential hazards.
- The possible relation between primary liver cancer and sewage exposure deserves further investigation.

MATERIAL AND METHODS

We studied two occupational cohorts, one made up of wastewater workers, the other (the control cohort) of water supply workers. All cohort members were male blue collar workers. The two cohorts were compared in terms of cause specific mortality and cancer incidence.

The cohort of wastewater workers

This cohort included 591 workers who had, for any period between 1 January 1965 and 4 June 1996 been employed

Table 1 The mortality of wastewater workers relative to that of water supply workers 1965–97 (inclusive); number of deaths (n) and relative risk estimates (RR) with 95% CI, by underlying cause of death

Cause of death (ICD-7)	n	RR	(95% CI)
Total	150	1.25	(1.03 to 1.51)
Cancer (140–205)	45	1.34	(0.95 to 1.89)
Cardiovascular disease (330–4, 400–68)	48	1.06	(0.76 to 1.47)
Other diseases	39	1.39	(0.95 to 2.01)
External causes (800–999)	17	1.44	(0.80 to 2.58)
Cause of death unknown*	1	0.94	(0.10 to 8.79)

*Death certificate not available because the person died during a (temporary) stay outside Denmark.

either at the sewerage department of the municipality of Copenhagen or at the two wastewater treatment plants of the municipality of Copenhagen. We identified people from the mailing lists of the previous health surveys in 1974 and 1976^{6,13} combined with census-type employment lists from the period 1965–96. A subject was entered into the study by the date at which the original list of identification was compiled. In case a person was fully identified in more than one list, he was enrolled into the study from the oldest one.

The control cohort

The cohort of water supply workers included 1545 workers who had for any period between 1 January 1965 and 31 December 1996 been employed at the waterworks of the municipality of Copenhagen. The water supply workers were identified from a currently run employment roster, from which no data have been deleted since the roster was set up more than 80 years ago. The water supply workers were entered into the study on 1 January 1965 or the date of first employment, whichever occurred latest.

Follow up

The cohort members were followed by registry linkage using the unique personal identification number or, if this was not available, the person's birthday, name, and address. The follow up regarded vital status, emigration, or officially registered disappearance. People were followed from their enrolment into the study and until the date of death, emigration, registered disappearance, or until 31 December 1997, whichever occurred first.

Of the 591 wastewater workers, 434 were still alive and living in Denmark by the end of follow up on 31 December 1997, 150 had died, six had emigrated, and one had disappeared. Of the 1545 water supply workers, a total of 1007 men were still alive and living in Denmark, 524 had died, 12 had emigrated, and two had disappeared. The number of person-years at risk covered by the study was 8174 for the wastewater workers and 28 778 for the water supply workers.

We matched our cohort membership lists with the Danish death certificate registry and with the Danish Cancer Registry. The death certificate registry, which covers the whole population, includes data on causes of death (underlying, contributory, and other diseases that may also have been of importance) with diagnoses coded according to the version of the International Classification of Diseases (ICD) in use by the time a death occurred (ICD-7, ICD-8, and ICD-10 respectively), manner of death, date and place of death, and the postmortem examination record if available. We transformed all death certificate codes to ICD-7. The Danish Cancer Registry also covers the whole population and includes diagnosis (including coding according to ICD-7 and to ICD-oncology if available), month and year of diagnosis, information about the diagnostic verification including pathology record if available,

Table 2 Cancer incidence among wastewater workers relative to that of water supply workers 1965–97 (inclusive); number of cases (n) and relative risk estimates (RR) with 95% CI, by cancer site

Diagnosis (ICD-7)	n	RR	(95% CI)
All malignant neoplasms (140–205)	68	1.27	(0.97 to 1.67)
Respiratory cancer (160–9)	20	1.65	(1.00 to 2.74)
Lung cancer (162.0–1)	17	1.48	(0.46 to 4.74)
Digestive cancer (150–9)	14	1.38	(0.71 to 2.71)
Primary liver cancer (155)	4	8.9	(1.5 to 51.5)

information about treatment, cause of death if relevant, and postmortem examination record if available.

From the "Statens Serum Institut" we also obtained data on registered notifiable infectious diseases from 1980 onwards, but the data obtained were deemed too scant for reporting.

Comparisons

Comparisons between wastewater workers and controls were based on a Cox regression model accounting for the observed number of person-years at risk in age and period specific cells.

In addition to these cohort versus cohort comparisons, the wastewater workers' mortality was also evaluated against national death rates (age and period specific rates for 1965–97 for all Danish males) and regional death rates for unskilled blue collar workers (age and period specific rates for 1970–92 for males employed in unskilled jobs in Greater Copenhagen on 9 November 1970), while the wastewater workers' cancer incidence was evaluated against national cancer incidence rates for 1963–95 (specific for gender, age, and period). The latter comparisons were based on observed versus "expected numbers"; because of the size and type of the data, the statistical evaluation was based on the assumption that the distribution of the observed events follows a Poisson pattern.

RESULTS

A total of 150 deaths occurred among the wastewater workers, while 524 deaths occurred in the control group. Death certificate information was obtained for all but five deaths (one wastewater and four controls). The overall mortality observed in the wastewater group significantly exceeded the mortality of the control group (table 1). The increase seen for diseases other than cancer and cardiovascular diseases ("other diseases") was due to no single diagnostic group. Infectious diseases were notified as the underlying cause of three deaths, two of which occurred in wastewater workers (diagnoses: tuberculosis, and staphylococcal sepsis, respectively), while the third death (due to gastroenteritis) occurred in a control. Two wastewater workers and 12 controls died from liver cirrhosis.

Within the study period, 68 new cancer cases occurred among the wastewater workers, while the incidence in the control group numbered 231 cases. The cancer risk of the wastewater workers exceeded that of the controls, but the difference did not reach statistical significance (table 2). With regard to the cancer sites pointed out in previous studies on wastewater workers, we found no cases of nasal cancer in the wastewater group, while three cases occurred in the control group. Laryngeal cancer occurred in two wastewater workers and seven controls. Stomach cancer occurred in two wastewater workers and eight controls. Four wastewater workers and two controls developed a primary liver cancer (specific diagnoses: hepatocellular carcinoma (ICD-7 no. 155.0) in two wastewater workers and one control, and biliary tract cancer (ICD-7 nos 155.1–155.8) in another two wastewater workers

Table 3 The mortality of wastewater workers 1965–97 (inclusive) relative to that of all Danish males and unskilled blue collar male workers in Greater Copenhagen; standardised mortality ratio (SMR) with 95% CI, by underlying cause of death

Cause of death (ICD-7)	Wastewater workers compared with:			
	All Danish males		Unskilled Copenhagen male workers	
	SMR (%)	(95% CI)	SMR (%)	(95% CI)
Total	138	(117 to 162)	111	(94 to 131)
Cancer (140–205)	160	(117 to 214)	122	(89 to 163)
Cardiovascular disease (330–4, 400–68)	98	(72 to 130)	94	(70 to 123)
Other diseases	175	(124 to 239)	111	(79 to 152)
External causes (800–999)	203	(118 to 325)	133	(77 to 213)

Table 4 Cancer incidence among wastewater workers 1965–95 (inclusive)* relative to that of all Danish males; standardised incidence ratio (SIR) with 95% CI, by cancer site

Diagnosis (ICD-7)	SIR (%)	(95% CI)
All malignant neoplasms (140–205)	150	(117 to 190)
Respiratory cancer (160–5)	209	(127 to 322)
Lung cancer (162.0–1)	203	(118 to 325)
Digestive cancer (150–9)	134	(73 to 225)
Primary liver cancer (155)	526	(143 to 1348)

*National cancer incidence rates were not available for the last two years of cohort follow up (1996–97).

and one control). Prostate cancer occurred in five wastewater workers and 23 controls.

With regard to the additional comparisons based on external standards (national rates and regional rates for blue collar workers, respectively), changing the standard of reference was seen to affect the magnitude of the “effect” estimate, but did not alter the general pattern observed. The mortality analyses indicated an overall increase (total mortality), and increases for cancer, “other diseases”, and external causes of death, while no mortality difference were seen for cardiovascular disease (table 3). The cancer incidence among the wastewater workers significantly exceeded the national average, with primary liver cancer standing out (table 4), just as it did in our cohort versus cohort comparisons.

DISCUSSION

Apart from the finding of an increased risk of primary liver cancer, our results are rather unspecific, indicating a suboptimal state of health among the wastewater workers. Previous studies based on questionnaires or interviews have shown a high prevalence of gastrointestinal symptoms among wastewater workers, an issue that could not be addressed in our study on mortality and cancer incidence. Our findings indicate, however, that if the agents responsible for the gastrointestinal symptoms have a bearing on the wastewater workers’ risk of fatal diseases, the effect seems to be highly unspecific.

Validity issues

Our results reflect the combined effect of occupational exposure and non-occupational factors. In particular, the comparisons with external standards (population rates) reflect well known geographical and socioeconomic trends in addition to the differences between a stable occupational group, the total group of blue collar workers in unskilled jobs, and the total population.

We compared the cohort of wastewater workers with a cohort of water supply workers because we were interested in possible long term health effects of wastewater. By choosing the local water supply workers as standard of reference for the wastewater workers, we have focused on the exposure contrast and have neutralised sources of strong bias such as “the healthy worker effect” and social class differences, as both groups of workers are employed in physically demanding jobs and belong to the same socioeconomic class. Further, the wastewater workers and the water supply workers are employed by the same Copenhagen municipality authority and are comparable in terms of formal employment conditions. Another important feature is that both worker groups are known to be extremely job stable, with a low turnover.

With regard to differences that may have confounded the comparisons, many of the water supply workers have worked in pumping stations outside the metropolis, while most of the wastewater workers have had their daily work in highly urbanised areas with air pollution from heating, industry, and traffic. Further, we cannot be completely sure that the two groups have been similar in terms of lifestyle habits, although such habits tend to be closely correlated to socioeconomic class. If the two worker groups differed in terms of, for example, prevalence of heavy smokers, the results for smoking related diseases would be biased—upwards or downwards. We have no data that allow us to determine whether smoking has biased our relative risk (RR) estimates for smoking related diseases, but the overall prevalence of smoking is high among Danish blue collar workers, and in consequence, a (hypothetical) difference should be rather extreme to explain a RR = 1.5 for lung cancer. The fact that no difference was seen for cardiovascular diseases or for cirrhosis supports the assumption that our results are not seriously biased by lifestyle differences.

Regarding possible misclassification, the quality of the information about individual outcomes was independent of the exposure under study. Non-differential diagnostic misclassification may, however, have affected the “cause of death” distribution: about one third of the Danish death certificate diagnoses are incorrect, with too many deaths being ascribed to common diagnoses such as ischaemic heart disease at the expense of other, more subtle diagnoses.¹⁵ This type of misclassification will bias the RR estimate for ischaemic heart disease (and other diseases that are over represented on death certificates) towards unity.¹⁶ Thus, it is possible that the RR estimate for cardiovascular mortality (RR = 1.06) may cover real mortality differences, favourable or unfavourable. With regard to the data on cancer incidence, these are considered quite reliable except for non-melanoma skin cancer, for which the registration is known to have a low coverage.

Unfortunately, our identification data did not allow us to analyse the possible effect of period or duration of employment, neither could we single out specific work area hazards.

Our findings represent an average and we may have missed important information.

Cancer risk

We could not confirm prior findings of increased risks for nasal, laryngeal, stomach, or prostate cancer. However, our finding of four cases of primary liver cancer in less than 600 wastewater workers is remarkable as this cancer site is rare in Denmark (standardised annual incidence rate for men in Copenhagen 1973–77: 5.9 per 100 000). We find this worth noting, particularly as an increased risk of primary liver cancer has previously been reported for sewage plant workers.⁹

Two of the four liver cancer cases in our study were hepatocellular carcinomas (ICD-7 no. 155.0), while the other two were biliary tract cancers (ICD-7 nos 155.1–155.8), a heterogeneity similar to that reported by Lafleur and Vena in their study on Buffalo sewage plant workers.⁹ Adhering strictly to the conventional criteria for causal interpretation, the finding of two histologically different types of cancer should detract from the credibility of a causal hypothesis, because the specificity criterion cannot be met.¹⁷ However, a chemical precarcinogen may give rise to both hepatocellular carcinomas and biliary tract cancers, because after being activated in the liver cell, the carcinogen is likely to be excreted into the bile. The most potent liver precarcinogen known is aflatoxin B₁, a mycotoxin produced by certain *Aspergillus* species. Together with chronic hepatitis B and C, the ingestion of aflatoxin contaminated crops is believed to be responsible for the epidemic of liver cancer in poor parts of the world. We have no knowledge about a possible aflatoxin exposure of the Copenhagen wastewater workers, but putrid sludge screened from wastewater may provide ideal (warm and humid) growth conditions for moulds, and sludge composting has been shown to involve heavy exposure to spores of *Aspergillus fumigatus*,¹¹ while the aflatoxin producing *Aspergillus flavus* has recently been identified in a Malaysian sewage treatment plant.¹⁰

Industrial wastewater may also contain substances that are carcinogenic or toxic to the liver, and hygienic measurements from the 1970s and 1980s have documented the presence of halogenated solvents in the Copenhagen sewers.^{6, 12}

Chronic infection with hepatitis B or C is associated with an increased risk of liver cirrhosis and hepatocellular carcinoma, processes that are hastened by excessive alcohol intake. Both hepatitis B and C are rare in Denmark and we found no registrations of these diseases among the wastewater workers in 1980–97; neither were any HBsAg carriers found in the 1976 survey of Copenhagen wastewater workers.¹⁴ Further, we found no excess of liver cirrhosis among the wastewater workers, indicating that drinking habits do not “explain” the observed excess of primary liver cancer.

CONCLUSIONS

We have found a slightly increased mortality and cancer morbidity among Copenhagen wastewater workers, and we think that occupational exposures may have contributed to these findings. Our results suggest that occupational agents may confer to the wastewater workers an increased risk of a cancer that is rare in our society—primary liver cancer—and we find that this topic deserves further investigation.

For preventive purposes, the workers’ exposure to sewage and sludge should be minimised, an objective that may be achieved by giving information to the workers combined with a thorough hygienic scrutiny of every installation and work procedure.

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